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Jesuit Geophysical Observatories

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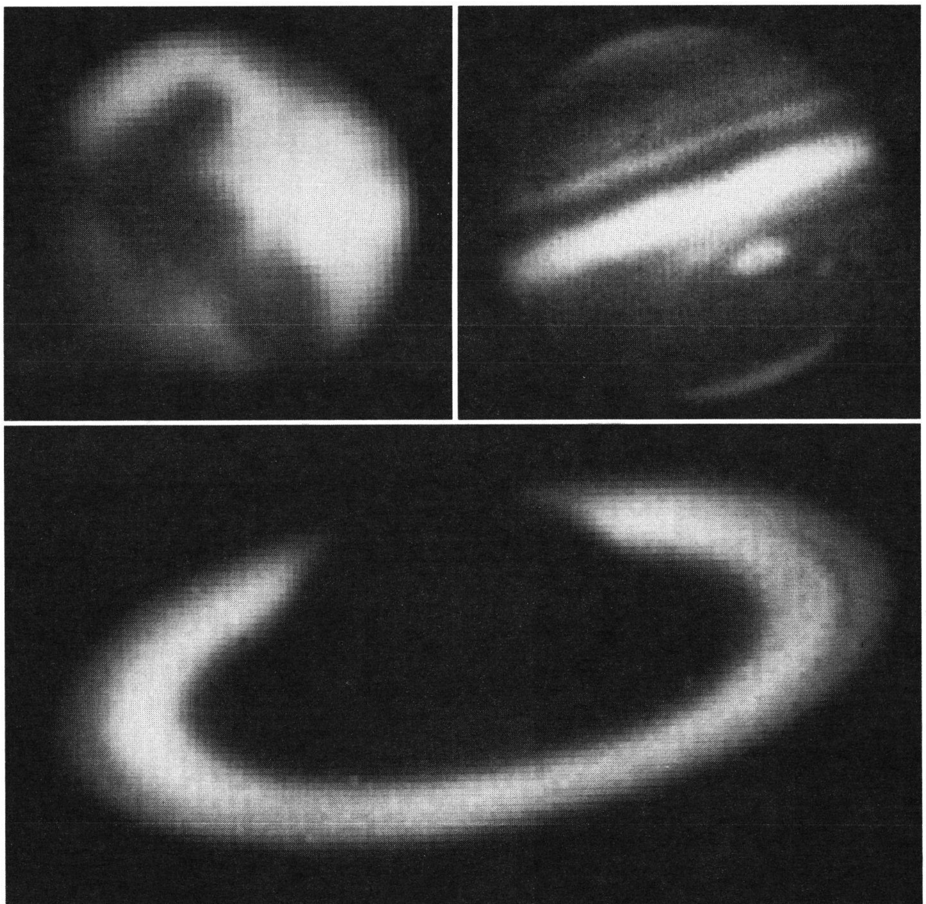
Jesuits have had an interest in observing and explaining geophysical phenomena since this religious order, the Society of Jesus, was founded by Ignatius of Loyola in 1540. Three principal factors contributed to this interest: their educational work in colleges and universities, their missionary endeavors to remote lands where they observed interesting and often as yet undocumented natural phenomena, and a network of communication that brought research of other Jesuits readily to their awareness.

One of the first and most important Jesuit colleges was the Roman College (today the Gregorian University) founded in 1551 in Rome, which served as a model for many other universities throughout the world. By 1572, Christopher Clavius (1537–1612), professor of mathematics at the Roman College, had already initiated an important tradition of Jesuit research by emphasizing applied mathematics and insisting on the need of serious study of mathematics in the program of studies in the humanities. In 1547 he directed a publication of Euclid's work with commentaries, and published several treatises on mathematics, including *Arithmetica Practica* [1585], *Gnomonicae* [1581], and *Geometrica Practica* [1606]. Clavius was also a Copernican and supported his friend Galileo when he announced the discovery of the satellites of Jupiter.

Christopher Schreiner (1575–1650), a colleague of Clavius, installed the first telescope at the Roman College and carried out observations of sun spots. His book, *Rosa Ursina* (1631) includes a careful discussion of sun spots, the Sun's rotation, and observational methods. He was involved in a priority dispute with Galileo over the discovery of sun spots.

Athanasius Kircher (1601–1680), professor of the Roman College, greatly influenced the learned circles of Europe. Kircher was a universal genius who dedicated his interest to many subjects, among them geophysical phenomena and the deciphering of Egyptian hieroglyphics. The greater part of his observations and speculations relative to geophys-



New infrared detector technology *has made obtaining near infrared images of the planets much easier, according to David Rank of the University of California at Santa Cruz's Lick Observatory. A new generation of high-sensitivity large-format detector arrays that can extend the wavelength coverage into the infrared heralds a new era in Earth-based, airborne, and space-based remote sensing. These photos of Mars (top left), Jupiter (top right), and Saturn (above) were made with Lick Observatory's 3-m Shane telescope using the Lick infrared camera with a 128x128 HgCdTe NICMOS II detector donated by Rockwell International Science Center. The scale of the photos is 0.4 arcseconds per pixel, which is close to the diffraction limit of the telescope. Images such as these can be obtained at many wavelengths and combined to produce spectral image cubes that show how energy is absorbed and reflected as a function of wavelength, thus providing information on a planet's surface or atmospheric composition. Images contributed by David Koo, Kirk Gilmore, and David Rank of Lick Observatory, and Ted Roush at NASA's Ames Research Center.*

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ical phenomena are contained in his two works, *Mundus Subterraneus* [1665] and *De Arte Magnete* [1643]. In the first he proposed a system of fire conductors in the interior of the Earth that linked the volcanos with a central fire and related them with the occurrence of earthquakes; in the second, he collected observations of the magnetic declination throughout the world and speculated on the cause of the Earth's magnetic field.

During the 17th and 18th centuries, Jesuits made observations of meteorological conditions, magnetic declination, earthquakes, volcanic eruptions, and the aurora borealis. Even at this early date, meteorological observations included measurements of atmospheric pressure, temperature, humidity, and rainfall. Written accounts of these observations from the colleges of Lyon, Milan, Siena, and Prague during the 18th century are of particular interest. The occurrence of the aurora borealis visible at low latitudes was of special interest to Jesuit scientists in this age, among them Laurent Beraud (1702–1787), and Joseph Stepling (1716–1778).

Among the Jesuit scientists of this time, special mention must be made of R. J. Boscovich (1711–1787). Boscovich was a pioneer in differential geometry and developed a theory of matter in which atoms are considered as centers of force fields. In 1793 he published a book on the figure of the Earth, *Dissertatio de Telluris Figura*, in which he determined a value of 1/273 for the Earth flattening (difference between polar and equatorial radius of Earth/equatorial radius of Earth), and in 1741 published *De Inaequalitate Gravitatis in Diversis Terrae Locis* on the variations of gravity measurements. Together with another Jesuit, C. Maire, he made observations in 1755 to measure the length of the arc of latitude between Rome and Rimini.

Missionary work took Jesuits to such remote lands as India, China, and the newly discovered America, putting these missionary-explorers in contact with different cultures and natural phenomena seldom observed in Europe. During their long journeys, many of them carried out such observations as magnetic declination and determinations of latitude. Jose de Acosta (1539–1600) described and tried to explain phenomena observed in Mexico, Central America, and South America, such as the variation of the magnetic declination, the motions of the oceans, earthquakes, volcanic eruptions, climatic differences, and the types and causes of the winds. These he recounted in his book, *Historia Natural y Moral de las Indias* [1590].

One of the more interesting chapters of Jesuit scientific contribution concerns Mateo Ricci (1552–1610), a disciple of Clavius and missionary to China. Ricci arrived in China in 1583, and by means of his knowledge of mathematics and astronomy, gained acceptance into the Imperial Court. There he introduced western concepts of these sciences, and, among other things, helped revise the Chinese calendar. Far from Europe, and unaware of the Galileo dispute, his astronomy followed the heliocentric view he had learned from Clavius. His work was continued by other Jesuit mathematicians such as Johann A. Schall von Bell (1591–1669) and Ferdinand Verbiest (1623–1688), each of whom served in turn as President of the Imperial Council of Mathematics in Peking.

In the 18th century, Jesuit missionaries did cartographic work, conducted geodetic measurements, measured the magnetic inclination and declination, and observed other geophysical phenomena in China, Tibet, the Middle East, and Central and South America. The nascent geophysical sciences benefited greatly from the meticulous records kept worldwide by the Jesuits of those times. Their corporate contribution, as well as that of their confreres of more recent time, remain as yet to be fully documented and appreciated.

Modern Geophysical Observatories

The first modern Jesuit observatories—Stonyhurst (England) and Georgetown (Washington, D.C.) were founded in 1838. By 1930 there were more than 30 such observatories in operation throughout the world. Some of these were small, attached to a Jesuit college or university. Others were more important, sponsored by institutions whose names are linked to the history of geophysics, such as those mentioned below. Some of these observatories were primarily astronomical but carried out geophysical observations as well, while others were created specifically as meteorological, magnetic, or seismological observatories. Although most of these observatories combined different types of observations, they usually specialized in one field or another.

Meteorological Observatories

Observatories mainly dedicated to meteorology were founded by Jesuits with the aim of preventing damage from natural catastrophes (hurricanes and severe weather), especially in the Caribbean and Pacific. The first of these was the Observatory of Belen, Havana, Cuba, founded in 1857; Benito Vines (1837–1893) became its director in 1870. Under his directorship, the observatory was equipped with up-to-date meteorological instrumentation and in 1887 became the center of a telegraphic communication network of 20 meteorological stations throughout the Caribbean. For 20 years, Vines dedicated himself to patient meteorological observations of tropical hurricanes, allowing him to deduce several empirical laws concerning the circulation and movement of these storms and to accurately forecast the path and arrival times of important hurricanes in the Caribbean, saving many lives and safeguarding property. In 1890 the *Times Democrat* of New Orleans noted that Vines was "regarded by navigators and meteorologists all over the world as one of the most correct and reliable of weather scientists of the age."

The observatory was equipped with several barometers, thermometers, psychrometers, pluviometers, hygrometers, two Robinson anemometers, seven nephoscopes of different types, and a meteorograph, an instrument developed in Italy by the Jesuit Angelo Secchi (1818–1878), a pioneer in the modern science of astrophysics. The instrument allowed the simultaneous recording of the atmospheric pressure, temperature, relative humidity and the intensity and direction of the wind. Vines developed two types of instruments with modified barometers to detect the proximity of hurricanes. The observatory also had astronomical and geomagnetic equipment and a seismological station. Vines was succeeded by Lorenzo Gongoiti, M. Gutierrez Lanza, and J. Rafael Goberna. Operation of the observatory ended in 1961 due to the political changes in Cuba.

In the Pacific, similar work was carried out by the Manila Observatory, founded in 1865 by the Spanish Jesuits. This observatory was the first meteorological station in the Far East. Its founder and first director was Federico Faura (1840–1897). In 1884 the observatory passed from the private auspices of the Ateneo de Manila to government sponsorship but was staffed by the Jesuits. After the Spanish American War the American military governor confirmed the official character of the observatory in 1899. The observatory was equipped with standard meteorological instrumentation, including a Secchi meteorograph. To supplement its work, a network of meteorological stations was installed in the Philippine Islands. The observatory also had astronomical, seismological, and magnetic instruments. The first seismograph, a Vicentini, was replaced by Gray-Milne instruments in 1877; the astronomical instruments were installed in 1898. Operation of the observatory was interrupted in 1941 with the Japanese invasion.

The responsibility for meteorological observations in the Philippines was taken over by the Meteorological Service of the Philippines in 1945. Work of the Manila Observatory itself, still under the auspices of the Jesuits, was resumed in 1952 with new instrumentation, and with a move of the observatory to Baguio, north of Manila. The observatory continues its work today in the fields of radio astronomy, solar astronomy, geomagnetism, ionospheric physics, and seismology.

The Observatory of Zi-ka-wei, near Shanghai, China, was founded in 1873, also initially a meteorological observatory. While maintaining its principal function in meteorology, it soon developed research programs in geomagnetism, ionospheric science, and seismology. Under Marc Dechevrens (1845–1923), who developed a code for the transmission of meteorological data, a service of typhoon warnings was developed with telegraphic communication with other stations of the western Pacific. Dechevrens' code, further developed and improved by his successor, Louis Froc (1859–1932), was widely used by meteorological stations in the Far East. Froc, director of the observatory from 1896 to 1932, was known for studies of the nature and effects of typhoons. In 1920 he published his monumental work, *Atlas of the Tracks of 620 Typhoons* [1893–1919]. His

important gravimetric measurements in China and the Philippines and in 1947 published the book, *Development Moderne de la Gravimetrie*. The first seismograph, a horizontal Omori, was installed in 1904. The seismological instrumentation was improved through the years with, first, Wiechert instruments in 1909, Galitzin instruments in 1915, and Galitzin-Wilip instruments in 1932. A branch observatory, the Observatory of Zose, mainly dedicated to astronomy and geomagnetism, was founded in 1898. Both observatories were under Jesuit direction until 1950 when they were taken over by the communist government. The last director of Zi-ka-wei was Ernesto Gherzi (1886–1976), who studied the effects of hurricanes on microseisms and on the ionosphere.

In 1889 the Jesuits established an observatory near Tanarive, Madagascar, with sections of meteorology, magnetism, and astronomy. Its first director, Elias Colin (1852–1923) studied the climate of Madagascar with a network of 13 meteorological stations installed in 1891. He also contributed to geodetic measurements on the island. The observatory was destroyed by fire in an armed revolt against the French colonial government in 1891, but was rebuilt in 1898 and continued operation under Jesuit direction up to the time of the independence of Madagascar in 1960, when it was closed. A more modest observatory was founded in 1903 in Bulawayo, Rhodesia, dedicated mainly to meteorological and geomagnetic observations.

During the first half of the present century, meteorological observations were conducted by Jesuits in other observatories, such as those of Ebro and Cartuja in Spain; Bogota, Columbia; Cleveland and St. Louis in the United States; Puebla, Mexico; and Ksara, Lebanon. Many of these observatories were discontinued as government meteorological services were organized, or in some instances the Jesuit stations simply passed from private to government hands.

Geomagnetic Observatories

Geomagnetic observations conducted at Jesuit observatories have contributed data necessary to understand the Earth's magnetic field. At the Observatory of Stonyhurst, England, geomagnetic observations were initiated in 1858. Stephen J. Perry (1833–1889) and Walter Sidegreaves (1887–1919) gave strong impulse to this work through their research on the relation between magnetic variations and solar activity and by their magnetic surveys in many areas of Europe and Asia.

Perry was famous for his many scientific travels: to France and Belgium in 1868 for a magnetic survey; to Cadiz, Spain, in 1870 to observe a total solar eclipse; to the island of Kerguelen, South Africa, in 1874; and to Madagascar in 1882 to observe the transit of Venus. Other solar eclipses led him to the Lesser Antilles in 1886; Pagost, Russia, in 1887; and finally to French Guiana in 1889, where he died of a tropical illness. During his travels, he made numerous magnetic and astronomical observations.

Perry was often accompanied by Walter Sidegreaves, who succeeded him as director of the Stonyhurst Observatory. The observatory itself was equipped with a large equatorial telescope with a lens of 38 cm, and several smaller telescopes. It had a large spectroscope of four prisms built by Troughton and Simms, and another of six prisms by Browning and Hilger. The magnetic equipment was very complete with several magnetometers for relative and absolute measurements. The observatory was also active in astrophysical work, especially in the study of sun spots, solar protuberances, and stellar and solar spectrography. Seismographs were installed in 1908. Activity in the observatory declined, and it was finally closed in 1960.

In 1879, Jesuits founded the Haynald Observatory in Kalocsa, Hungary. The first director was Charles Braun (1831–1907), known for his ingenious instrumental inventions for meteorological and astronomical observations, such as a nephoscope, a micrometer to determine the passage of stars, and two types of spectroheliographs that allowed direct photographs of the whole image of the Sun. In the last years of his life he made a very careful determination of the density of the Earth using the Cavendish-Pogendorf method. His successor, Jules Fenyi (1845–1927) carried out careful observations of sun spots, granulations, protuberances, and fulgurations over a 20-year period. He developed an interpretation of solar protuberances in terms of currents of incandescent hydrogen gas at the surface of the Sun. The observatory was equipped with astronomical, spectroscopic, and magnetic instrumentation, and was directed by the Jesuits until 1948.

The Ebro Observatory in Terragona, Spain, was founded in 1905 by Ricardo Cirera (1864–1932), who previously was responsible for the magnetic observations at Manila Observatory between 1887 and 1891. Created specifically to study solar-terrestrial relations, the observatory's instrumentation for solar and geomagnetic observations was very complete. In 1955 the first ionospheric vertical sounder was installed, the only one in Spain for more than a decade. This equipment was replaced in 1966 and again in 1988 by new models. A long history of observations of geomagnetic variations, telluric currents, and solar activity has been collected in the 85-year existence of the observatory. The first seismographs were installed in 1906. These were replaced by Mainka instruments in 1910 and in 1965 by the standard long- and short-period seismographs. The observatory has preserved a policy of continual renewal of instrumentation and of international cooperation in scientific programs.

Seismological Observatories

Jesuits also installed a large number of seismological stations in many parts of the world. Many of the observatories already mentioned, such as those of Manila, Zi-ka-wei, Stonyhurst, and Ebro had seismological instrumentation since very early dates and were active in seismological research. In other cases, observatories were founded with seismology as the principal interest, or, though founded for other purposes, soon became very active in this science due to their location in active earthquake areas. The Observatory of Cartuja in Granada, Spain, for example, was founded in 1902 with sections in astronomy, meteorology, and seismology, but under the direction of M. Sanchez Navarro-Neumann (1867–1941) soon became a leading center in the study of the seismicity of Spain and in the development of seismological instrumentation. Navarro-Neumann took advantage of the observatory's location at the center of the active seismic region of southern Spain to study the earthquakes of the region in detail. In 1917 he published the first catalogue of earthquakes in Spain compiled with modern criteria. In 1975 the observatory was transferred to the control of the University of Granada.

In South America the frequent occurrence of large earthquakes that produce many casualties and extensive damage moved Jesuits to create a number of seismological stations in this region. The Observatory of San Calixto in La Paz, Bolivia, was founded in 1913 by Pierre Descotes (1897–1964). Publication of the *Seismological Bulletin* has continued without interruption since that date to the present. The observatory started with instruments of local design. These were replaced in 1929 by Galitzin-Wilip seismographs. At mid-century, Professor Charles Richter termed the LaPaz station the most important single station in the world both for its strategic location with respect to earthquakes in South America and for the quality of its data. Its instrumentation has been updated regularly and today is a modern seismological research center.

Created in 1941 by J. Emilio Ramirez (1909–1983), the Instituto Geofisico de los Andes Colombianos in Bogota, Columbia, still continues its important seismological work, especially concerning the seismicity and seismic risk in South America. The Instituto Geofisico replaced the older and more modest observatory of San Bartolome in Bogota founded by the Jesuits in 1923. Other Jesuit seismological stations in South America that functioned for shorter periods of time are those of Antofagasta, Chile, San Miguel, Argentina, and Sucre, Bolivia.

In other lands, Jesuit seismographic stations were established at Rathfarnham Castle in Ireland in 1916 and at Riverview in Australia in 1909. These stations came to be known for the studies of certain of their directors, Richard Ingrahm and Burke-Gaffney, respectively. A station was founded at Ksara, Lebanon, in 1919, and at Montreal, Canada, in 1952. In Ethiopia the station in Addis Ababa was entrusted to the Jesuits in 1957.

Jesuit Seismology in the U.S.

In the United States the entry of Jesuits into seismology owes its origin to one man—Frederick L. Odenbach (1857–1933)—a Jesuit physics professor at John Carroll University in Cleveland. He es-

tablished the first seismological station operated by the Jesuits in the United States in the observatory of John Carroll University in 1900. He then conceived the idea of creating a Jesuit network of seismographic stations across North America. Operation of the network began in 1911 under the name of the Jesuit Seismological Service, with 16 stations, 15 in the United States and one in Canada. The Central Station was in Cleveland. The stations had uniform instrumentation consisting of Wiechert 80-kg horizontal seismographs. At that time, this was the only homogeneous seismological network covering an entire continent. Individual stations processed their seismograms and sent the data to the Central Station, where a central bulletin was published, and the data forwarded on to the International Seismological Center in Strasbourg (BCIS), established in 1896. Data were centrally reported there and a program of routine location and publication of earthquake epicenters began. The assembled data, and the earthquake locations were and remain to this day a service and a source of data to investigators everywhere in their further study of the Earth and of earthquakes and their causes. Unfortunately, the interest was not uniform and sustained and the American Service ceased its operation in 1922.

The idea of a Jesuit network was again proposed by James B. Macelwane (1883–1956), who in 1925 succeeded in reorganizing the Jesuit network of stations into the newly formed Jesuit Seismological Association. Member stations were Canisius College, Buffalo; Loyola University, Chicago; John Carroll University, Cleveland; Regis College, Denver; Georgetown University, Washington, D.C.; Marquette University, Milwaukee; Spring Hill College, Mobile, Alabama; Loyola University, New Orleans; St. Louis University, St. Louis; Xavier University, Cincinnati; Gonzaga University, Spokane; Santa Clara University, Santa Clara; and Weston Observatory, Boston College, Boston. The Central Station was now established at St. Louis University where Macelwane created an important research group in seismology. He wrote many articles on seismological instrumentation and conducted studies of individual earthquakes. He was especially prominent in developing educational programs in geophysics and in encouraging students. His book, *Introduction to Theoretical Seismology: Geodynamics* was an early text in the field. Macelwane was succeeded as president of the association by Joseph Lynch (1894–1987) of Fordham, then by Daniel Linehan (1904–1987) of Weston Observatory, Boston College, and most recently by William Stauder of St. Louis University.

As the Central Station of the new association, St. Louis University through its recently established Department of Geophysics became a resource for graduate education in seismology for a number of Jesuits who then returned as directors to their own institutions. The Central Station assumed as well the responsibility on behalf of the JSA of collecting data from member stations and from other stations around the world, of locating earthquake epicenters, and publishing these to the worldwide seismological community. The Central Station continued this service until the early 1960s, publishing data complementary to like determinations by the U.S. Coast and Geodetic Survey, the International Summary in London, and the Bulletin of the Central Seismological Institute in Strasbourg. Then the advent of computers and the ability to handle much larger data sets rendered former methods obsolete and obviated the need of duplicate efforts in the location of earthquakes. At the present time, some of the stations have ceased operation, while others, such as Weston Observatory and St. Louis University have become active seismological research centers.

One measure of the contribution of Jesuits to seismology is given by the number of Jesuit stations that became part of the World Wide Standard Seismological Network (WWSSN) established in 1962. Of the originally selected 125 stations throughout the world, nine were Jesuit: Georgetown (GEO), Weston (WES), Spring Hill (SHA), St. Louis (FLO), Bogota (BOG), LaPaz (LPB), Baguio (BAG), Riverview (RIV), and Addis Ababa (AAE). In 1975, Bogota became the site of one of ten even more advanced Seismic Research Observatories (SRO), and LaPaz an abbreviated station (ASRO) of the same network.

Conclusion

The recent history of Jesuit observatories varies from case to case. Some ceased operation or became government centers when communist governments came into power, as was the case with Zi-ka-wei, Belen, and Kalocsa. Others were transferred to state universities due to the high cost of operation, lack of personnel, or growth of the governmental service making the work of the Jesuit observatory no longer necessary. A certain number, however, continue their work and in some cases have developed into research institutes of note. Among the Jesuit geophysical observatories still in operation, the most important are Manila Observatory, San Calixto Observatory in La Paz, Instituto Geofisico de los Andes Colombianos in Bogota, Ebro Observatory in Spain, St. Louis University, and Weston Observatory of Boston College.

The history of the Jesuit geophysical observatories forms an important chapter of the scientific activity of Jesuits. While only a few names have been mentioned here, a considerable number of Jesuits who work in these observatories with their non-Jesuit colleagues have made important contributions to the fields of meteorology, geomagnetism, and seismology since the Order was founded in 1540.

Scientists Need Political Literacy

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Scientists need to sharpen their political literacy to promote public and congressional awareness of science policy issues. This was the message of a panel of politically savvy scientists at a recent workshop at the American Association for the Advancement of Science's annual meeting in Washington, D.C. Researchers can maximize their lobbying efforts by targeting critical points of the legislative and federal funding cycles, the panel said, and by understanding the differences between the science and policy processes.

Drastic modifications to the federal budget process this year will influence how much funding flows to research and development. A new feature for FY 1991–1993 is caps on federal expenditure in three areas: defense, foreign aid, and domestic "discretionary" spending. (Most of the agencies that fund geophysics fall into the domestic category.) Money cannot now be transferred from one of these areas to another, said Michael L. Telson, analyst for the House Budget Committee, and loopholes will be "very tough to find." What is more, non-defense discretionary spending has dropped over a decade from 24% of the budget to the present 15%. Another new requirement is the "pay-as-you-go" system. Under this, a bill that calls for an increase in "entitlement" or other mandatory spending must offset this by higher taxes or by a cut in other spending.

In the present budget climate, the outlook is poor for research and development funding that would carry over from one year to the next, said Norine E. Noonan, chief of science and space programs at the Office of Management and Budget. "Multi-year appropriations, at least in my view, are not in the cards right now," she said, citing this as a very serious problem for science funding.

Correct timing is vital to shaping the budget process. Noonan advised scientists to start their lobbying with the federal agencies. The federal budget is in the hands of OMB for only eight weeks or so, while the federal agencies work on their budgets for many more months. "We're happy to talk to anyone who walks in the door," Noonan said, "but by the time the budget gets to us from the agencies, it's over," for proposals have "pretty much been through the mill."

In both the legislative and executive branches, the testimony of a society or group carries greater weight than an individual opinion. Once a group's representative meets with a legislator's staff, they can play an important role in swaying their boss, explained Dana Isherwood, legislative analyst at Lawrence Livermore Laboratory and a former AAAS Congressional Fellow. Always leave behind a one-to-two-page fact sheet in the representative's office after a visit, she advised.

The panel saw plenty of room for scientists to improve how they interact with the federal government. Isherwood criticized scientists who refuse to set budget priorities